Anti-Neutrino Quasi-Elastic Scattering in MINERvA

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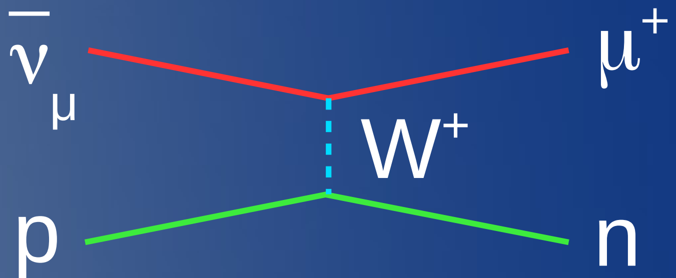
Overview

- Description of Quasi-Elastic (QE) Scattering
- Physics Motivation
- The NuMI Beam and MINERvA Detector
- Results
- Outlook

What is Quasi-Elastic Scattering?

$$\bar{\nu}_\mu + p \rightarrow \mu^+ + n$$



- Neutron is ejected from the nucleus, but not necessarily observed
- Incoming neutrino energy and momentum transfer can be reconstructed with just the muon kinematics
- Cross section can be calculated using the axial vector form factor (Dipole Approximation below)

$$F_A(Q^2) = \frac{-g_A}{\left(1+\frac{Q^2}{M_A^2}\right)^2} \qquad M_A = Axial\,Vector\,Mass$$

Motivation

- Uncertainties on neutrino interaction cross sections are a significant systematic error for neutrino oscillation experiments
- If mixing parameter θ_{13} is non-zero, experiments like NOvA may be able to measure leptonic CP violation
  - Could describe matter-antimatter asymmetry in the universe
  - Need well understood cross-sections for neutrino and anti-neutrino interactions

The NuMI Beam Line

- Neutrinos created from pion and kaon decays
- Ability to predict pion and kaon production off the target is the largest uncertainty in determining our flux

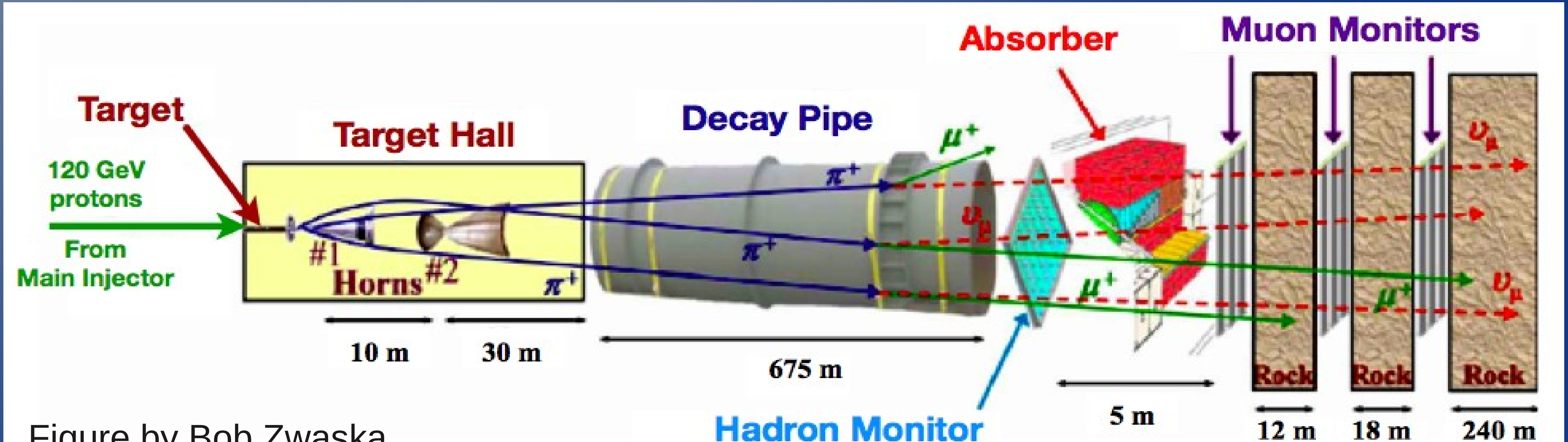
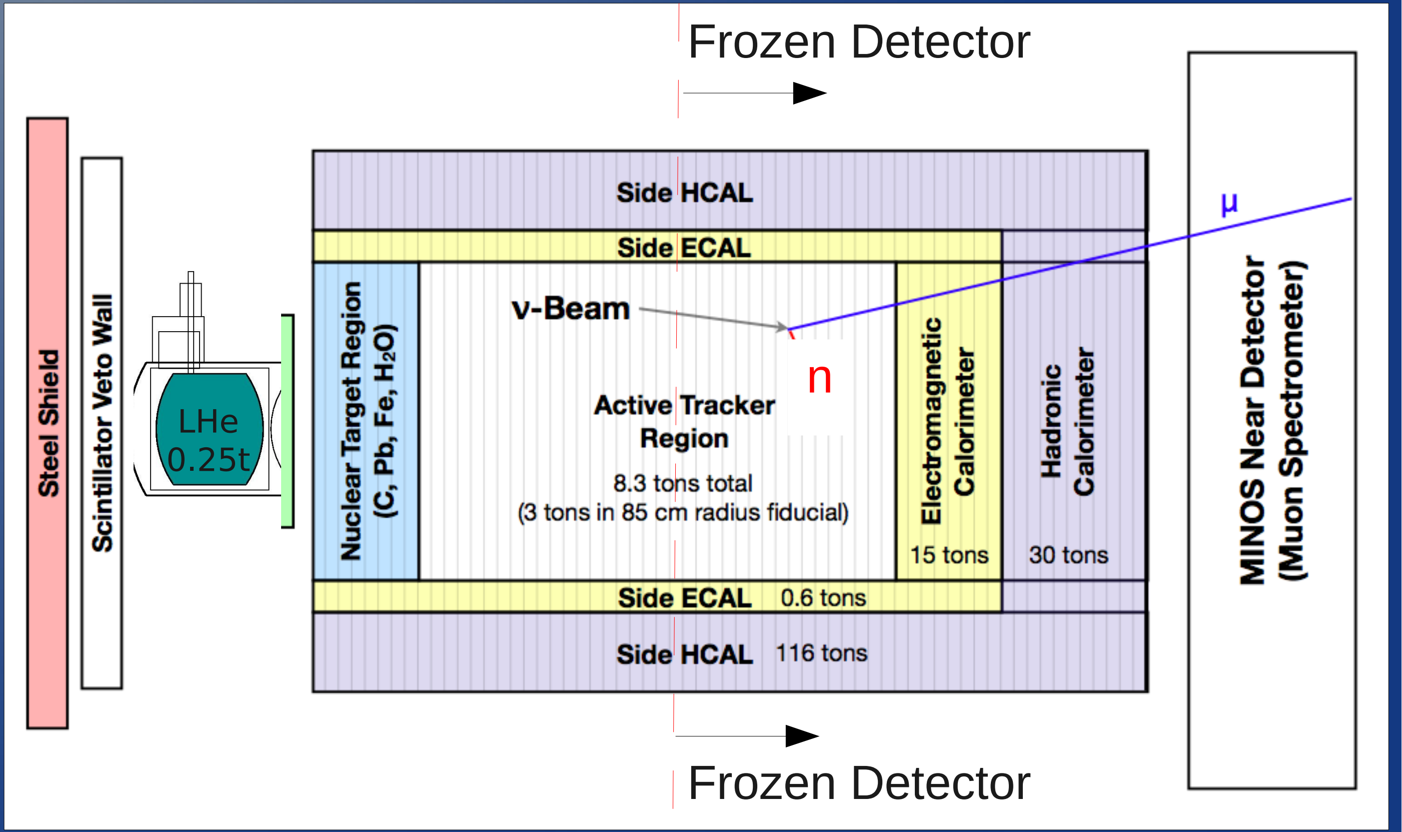


Figure by Bob Zwaska

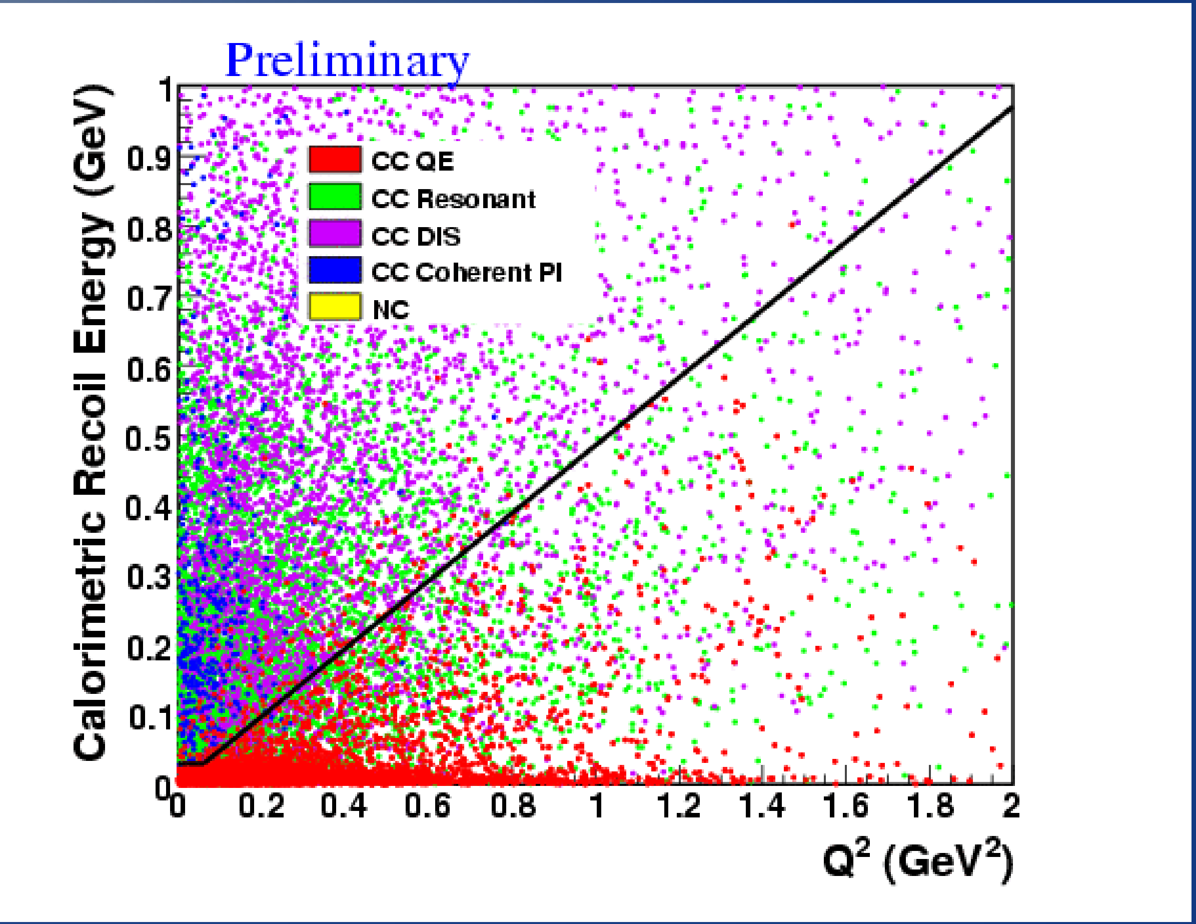
The MINERvA Detector

- Fine grained detector that lies upstream of the MINOS Near Detector (our muon spectrometer)
- Data that we show is from our partially constructed detector
- We show 4e19 POT worth of anti-neutrino data (~15% of total number of events)



Selecting a QE Rich Sample

- For quasi-elastic scattering, $Q^2 = 2m_p\nu$, where ν is the energy transfer to the hadron
- We summed all energy 5 cm away from the muon track and defined this as the recoil energy
- We then made a recoil cut that scales with $Q^2/2m_p$



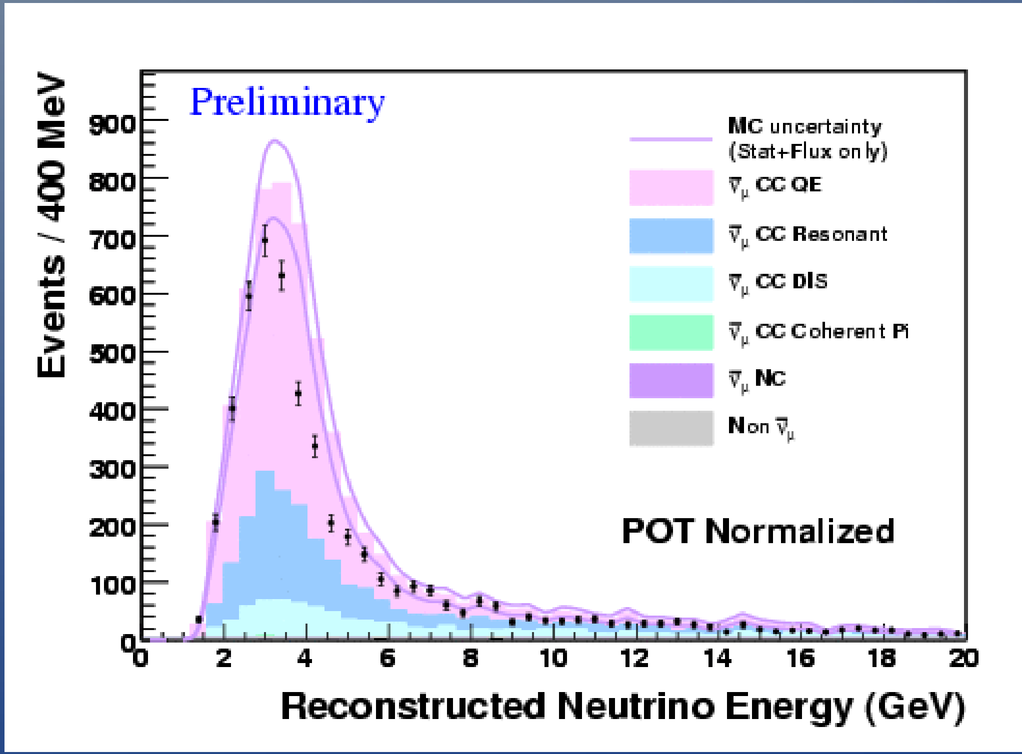
Neutrino Energy and Q^2

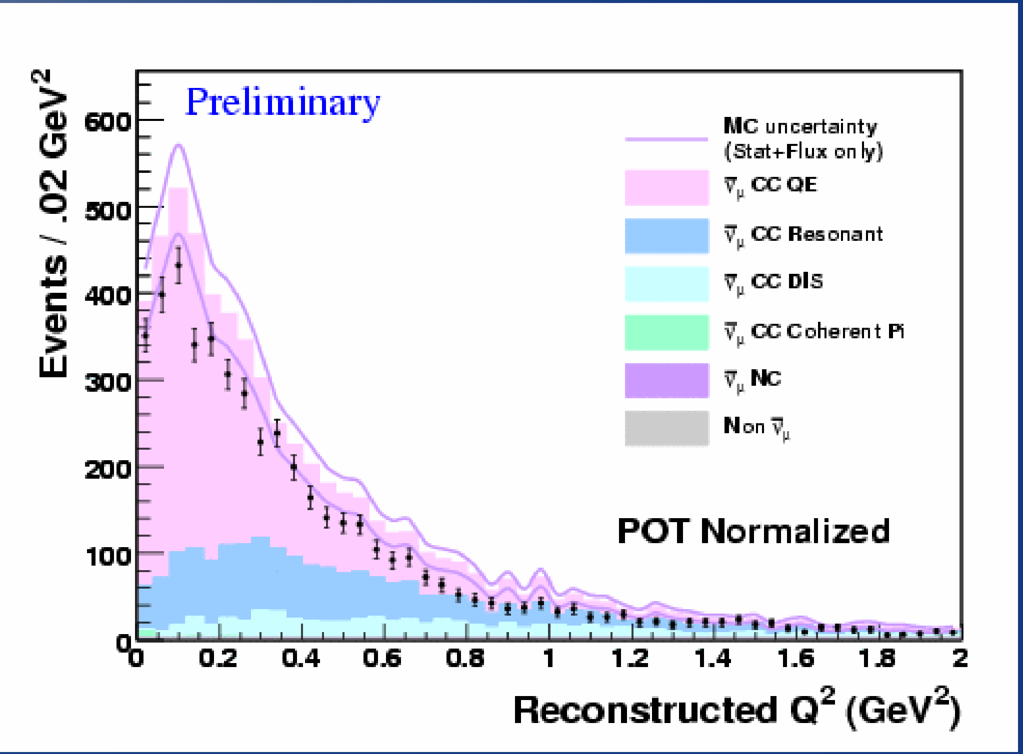
- Distributions are absolutely normalized and include flux errors

$$E_{\bar{\nu}_\mu}^{QE} = \frac{2M'_p E_\mu - (M'^2_p + m_\mu^2 - m_n^2)}{2(M'_p - E_\mu + \sqrt{E_\mu^2 - m_\mu^2}\cos\theta_\mu)}$$

$$M'_p = m_p - \varepsilon_B$$

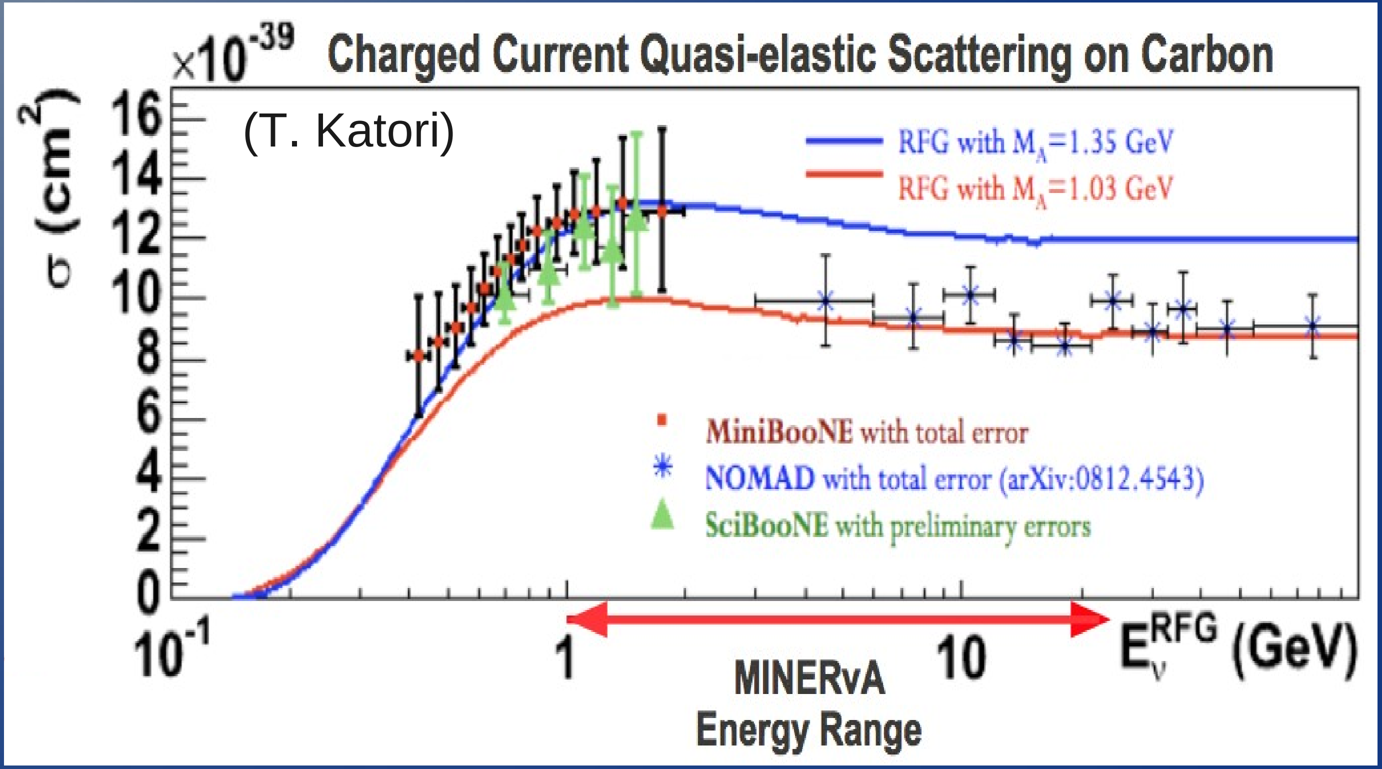
$$\varepsilon_B = 30\,MeV$$





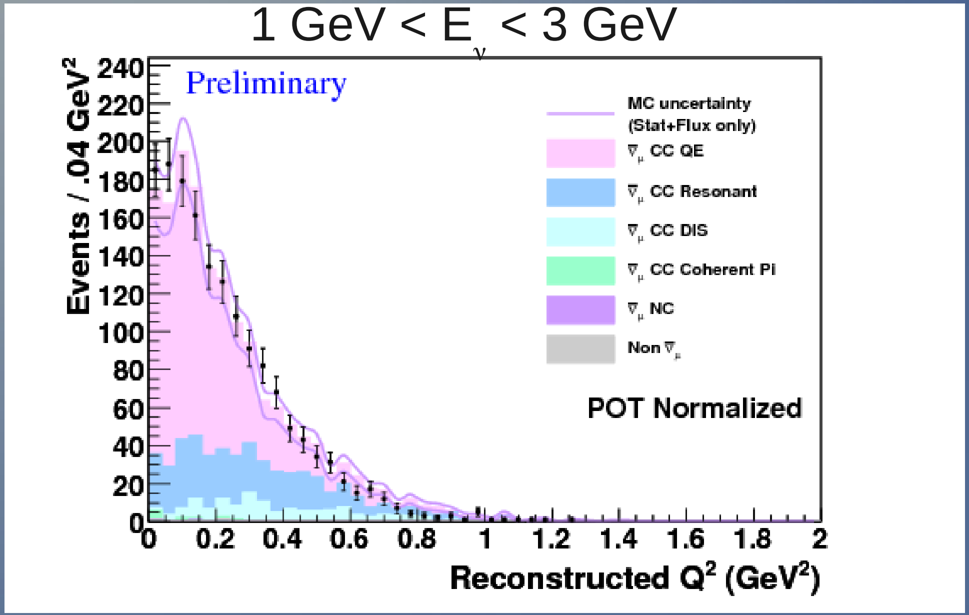
Recent World Cross Section Results

- Tension between various cross-section results
- Our simulation (GENIE 2.6.2) used M_A = 0.99 GeV
- Would M_A = 1.35 GeV found by MiniBooNE fit our data better?

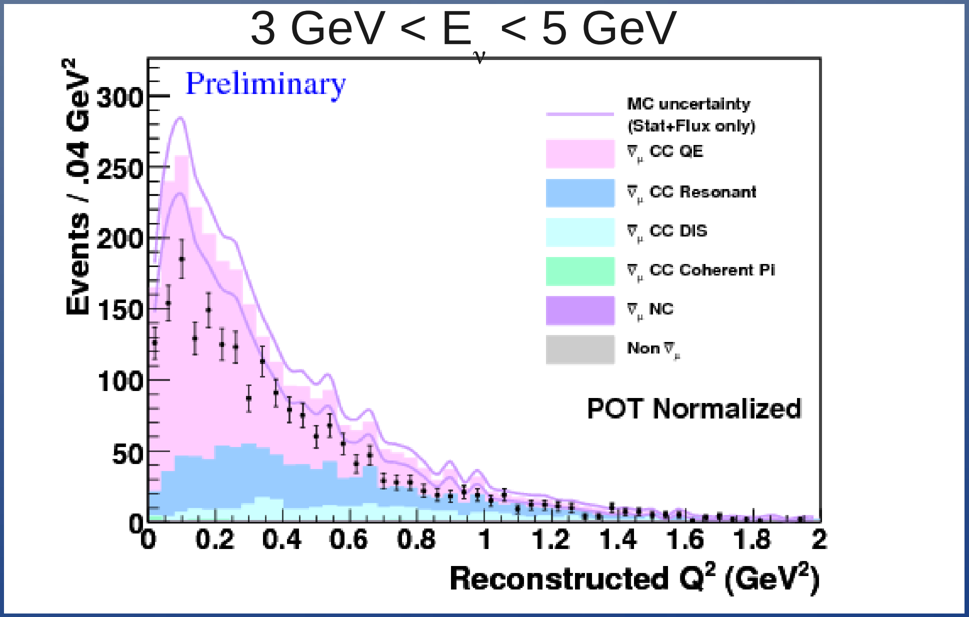


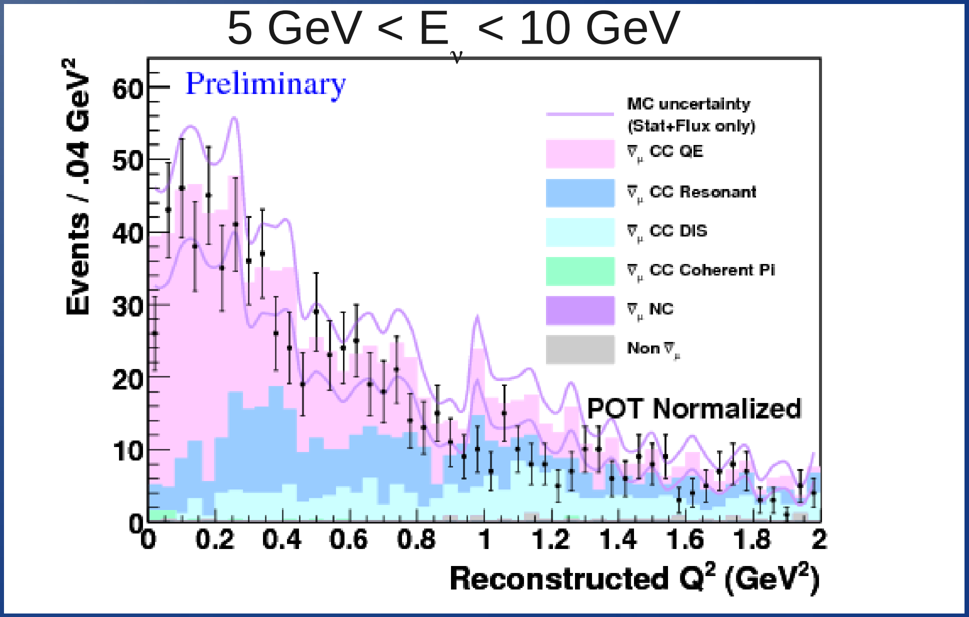
Note: Cross-sections are for neutrinos

Q^2 Separate by Energy



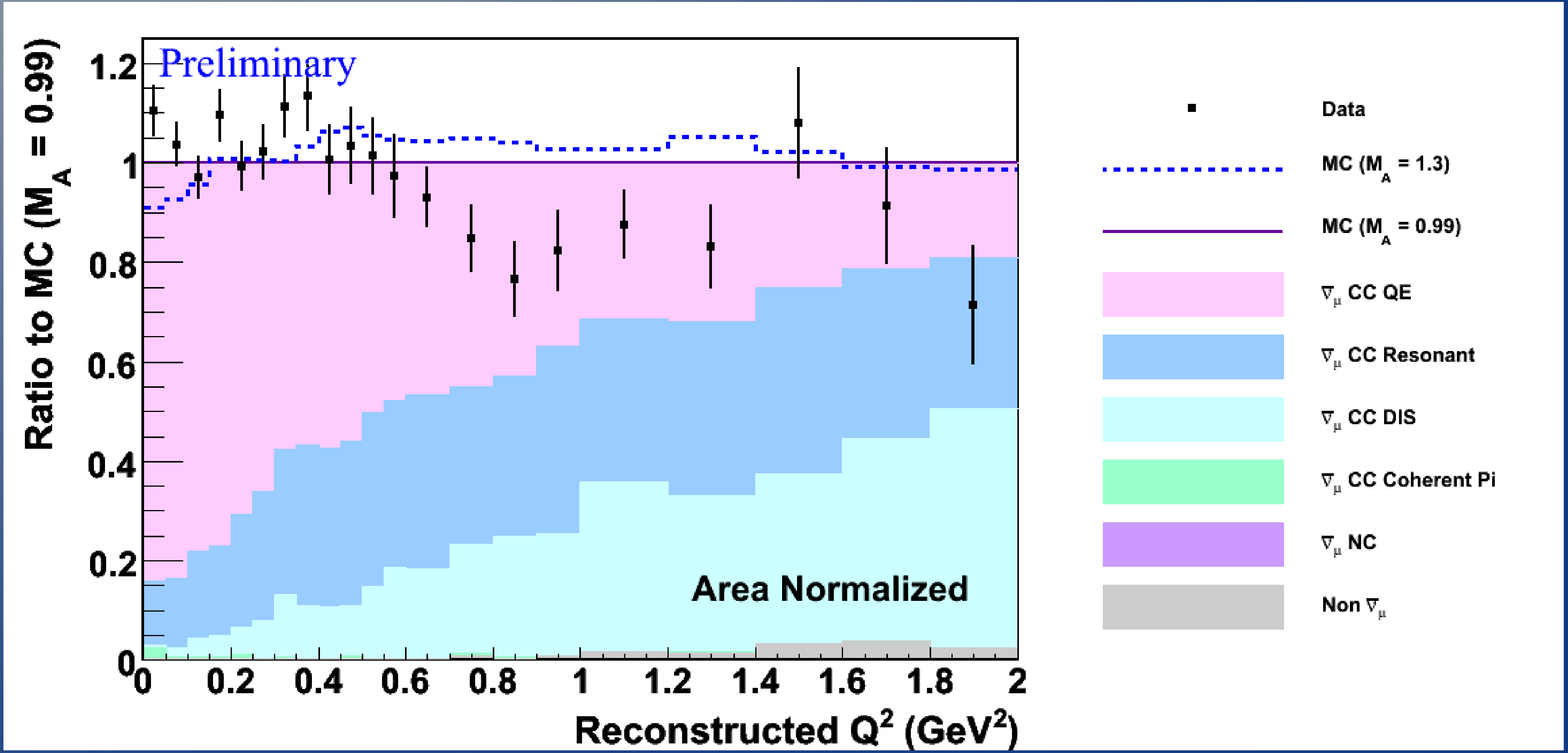
- Most discrepancy comes from the 3-5 GeV region
- For MiniBooNE M_A, expect more events across neutrino energies





Reweighted Q^2 Shape

- Reweighted Monte Carlo Q^2 distribution does not have better agreement with data



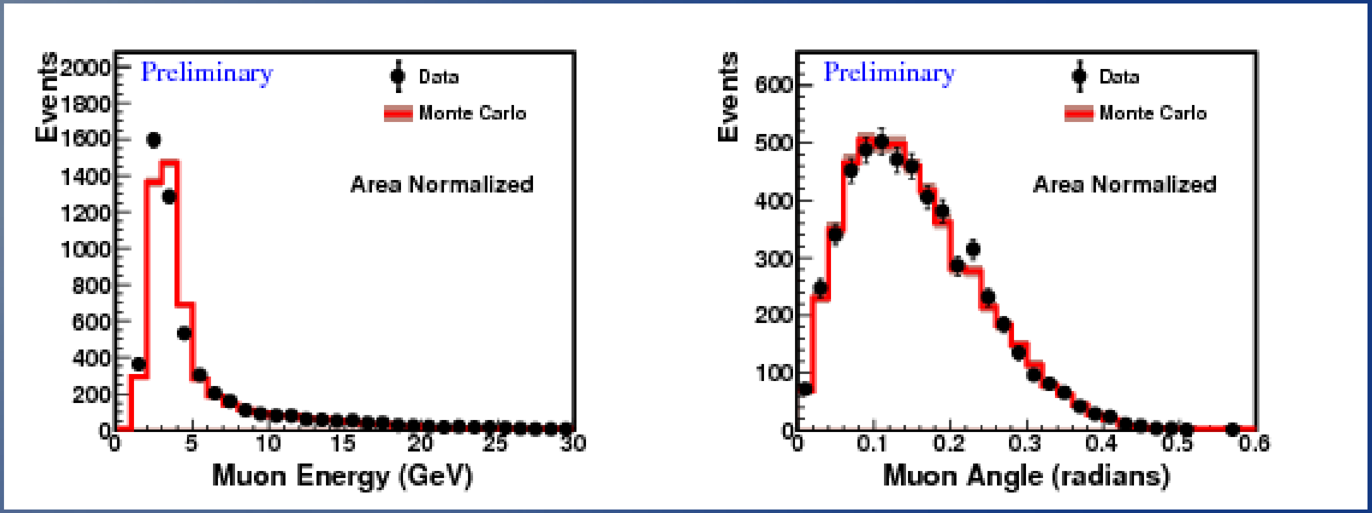
Outlook

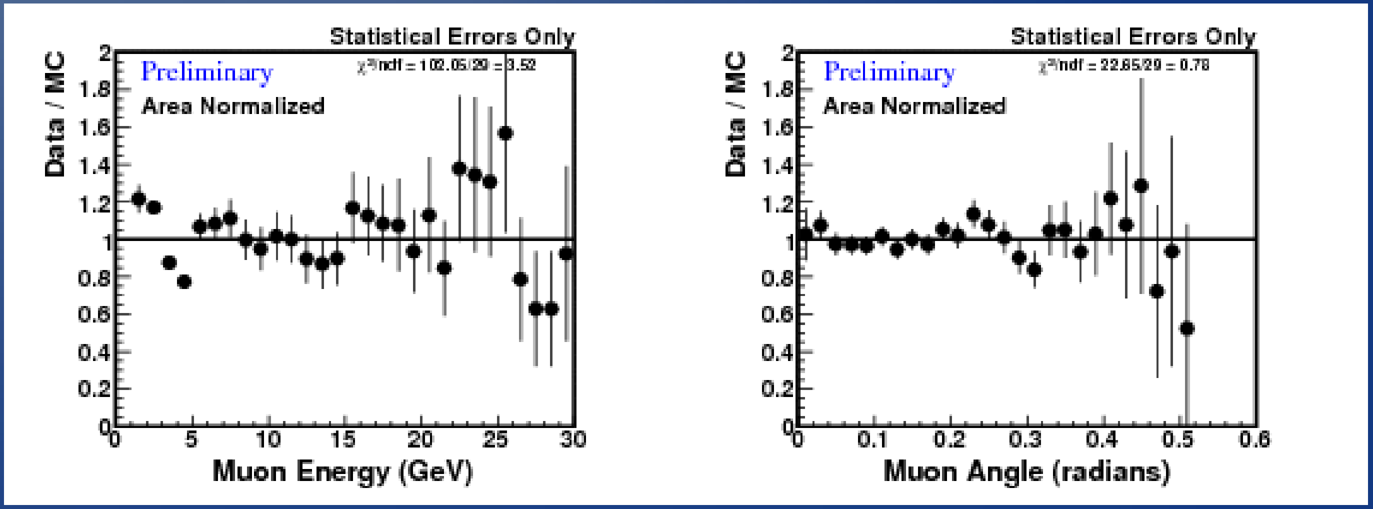
- Our data does not appear to favor a MiniBooNE value of M_A
- Will have distributions corrected for detector smearing soon to make more rigorous comparisons to MiniBooNE and NOMAD results
- Will incorporate additional data into the analysis
- Continuing to make strides in reconstruction and analysis techniques

Backup

Reconstructing QE Events

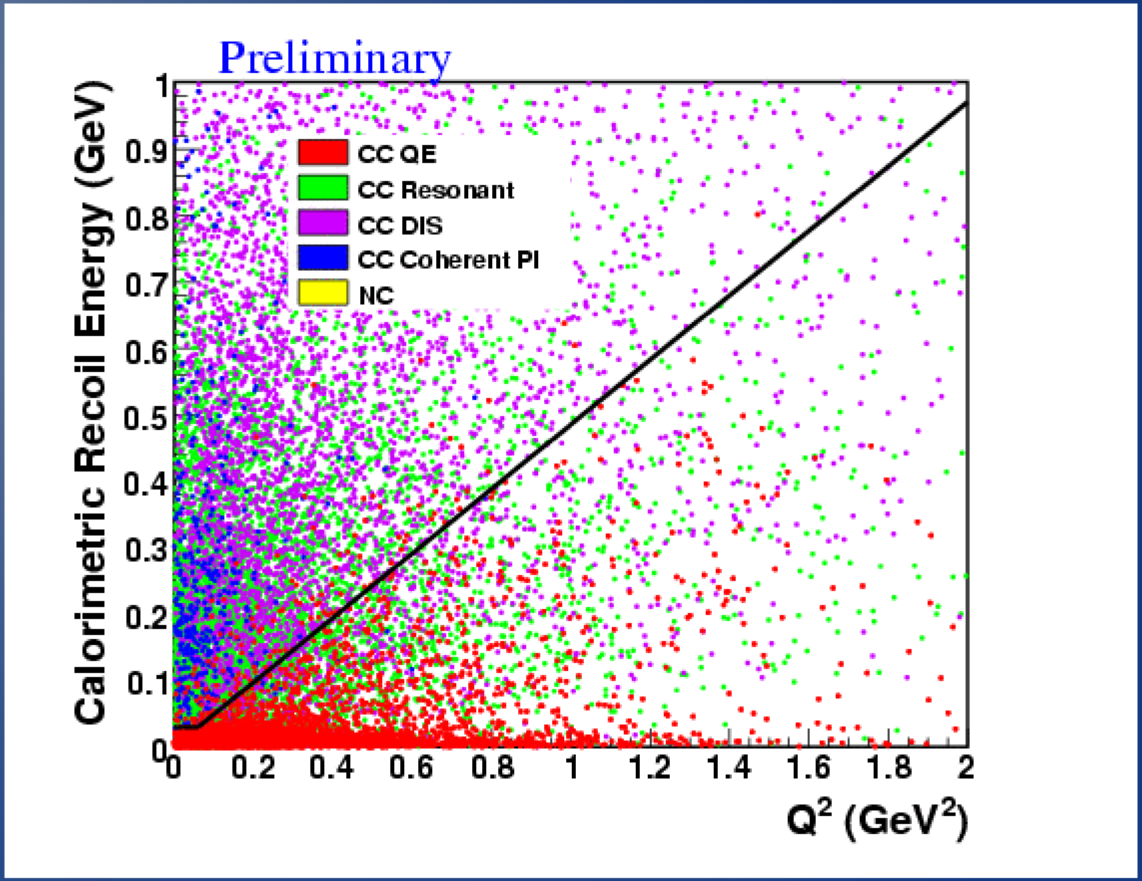
- Distributions are not corrected for smearing effects in the detector
- Good data/MC agreement for muon angle
- Discrepancy in muon energy likely comes from poor modeling of neutrino focusing peak



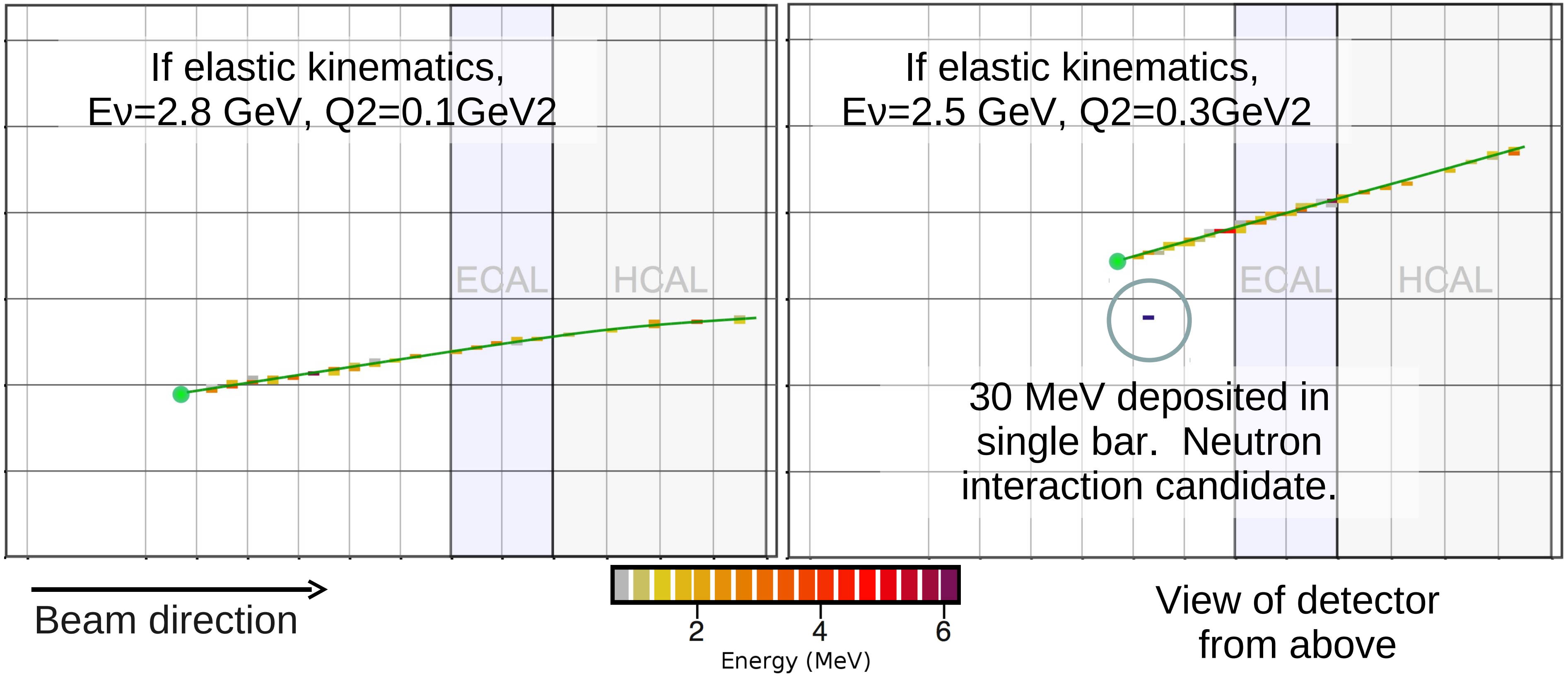


CCQE Selection Cuts

- Select tracks matched with muons in MINOS that have a vertex within our fiducial volume
- Apply a flat recoil cut of 0.03 GeV up to a value of Q^2 of 0.06 GeV^2
- Make a $Q^2/2m_p$ cut on recoil energy in the detector for Q^2 greater than 0.06 GeV^2

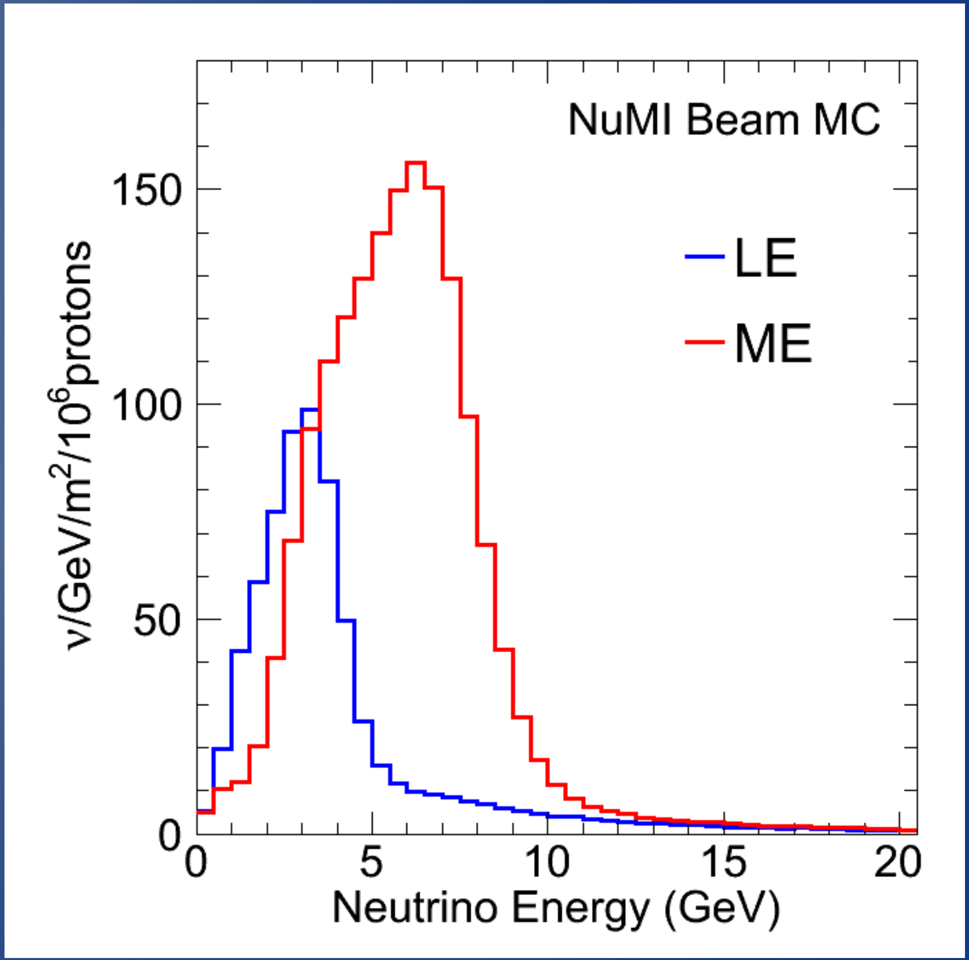


Example of QE Events in MINERvA (data)



NuMI Beam Flux

- ~35 E12 POT per spill
- Spill length/frequency = 10 μs/0.5 Hz
- Beam power: 300-350 kW
- Goal – 7% shape error, 10% normalization error



NuMI Beam Flux

Three strategies:

- Vary horn current and distance of target from horns, study how event rates change
- Measure muons from pion/kaon decays with muon monitors to predict pion/kaon production off the target
- Use world hadron production data to predict pion and kaon production